North American Journal of Fisheries Management 19:923–929, 1999

Influence of Electrofishing on the Mortality of Arctic Grayling Eggs

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Abstract.—The influence of electrofishing on egg mortality of Arctic grayling *Thymallus arcticus* was investigated. The hypothesis that electrofishing affects egg mortality was supported by two experiments. Experiment 1 examined the mortality rate of Arctic grayling eggs from parents that were electroshocked before spawning, and experiment 2 examined mortality rates of eggs that were electroshocked after fertilization. For experiment 1, egg mortality rates were significantly higher than the control group. The difference in mean mortality rates was 0.016 (SE = 0.005) compared to the control ($P = 0.022$). For experiment 2, mean egg mortality varied significantly ($P < 0.001$) by parents (electroshocked or not electroshocked), level of electroshock, and egg developmental stage. The largest difference in mean mortality rates compared with that of controls was 0.086 (SE = 0.017) for eggs electroshocked at the highest voltage gradient (1.30–1.50 V/cm), at 70 temperature units postfertilization, and from parents that were electroshocked before spawning. Under normal field conditions, only eggs in close proximity to an electrode would experience the highest level of electroshock used in this study. At other stages of development and at lower voltage levels (equivalent to being farther away from the electrodes), egg mortality rates were considerably less (typically <0.05). Arctic grayling eggs experienced less mortality before and after 70 temperature units postfertilization. The results of this study suggest that even in situations when the probability of exposure to electroshock is high, the cost to the population from using electrofishing to sample Arctic grayling is low.

Electrofishing is an effective method for capturing fish, particularly within river sections that are difficult to sample by other methods (Reynolds 1983; Clark 1985). Samples obtained through electrofishing are used to estimate abundance and age composition for Arctic grayling *Thymallus arcticus* in interior Alaskan rivers and streams (Ridder 1985; Clark 1995; Fleming 1995; Roach 1995). Inasmuch as sampling sometimes occurs near the time of spawning, fishery managers are concerned with the potential decrease to Arctic grayling spawning success from electrofishing.

Most electrofishing research has focused on physiological changes, injury, survival, and growth of fish exposed to electroshock (Hudy 1985; Gatz et al. 1986; Sharber and Carothers 1988; Mesa and Schreck 1989; Holmes et al. 1990; Roach 1992; Taube 1992; Hollender and Carline 1994; Mitton and McDonald 1994; Dwyer and White 1995; McMichael et al. 1998). Along with these studies, the effects of electroshock on spawning behavior and survival of eggs have received increased interest. Sorensen (1994) reported that goldfish *Carassius auratus* and brook trout *Salvelinus fontinalis* spawned normally with sexually active conspecifics within 24 h after being electroshocked. Females exposed to electroshock near the time of spawning, however, may produce less viable eggs. Muth and Ruppert (1996) exposed four ripe female razorback suckers *Xyrauchen texanus* to 10 s of 60-Hz current and three to 10 s of a complex pulse pattern. In both cases, survival of eggs was significantly lower than a control.

Godfrey (1957) and Marriott (1973) conducted some of the first experiments on survival of eggs after electroshock. These, along with more recent studies, suggest that eggs exposed to electroshock after fertilization may survive at lower rates than controls (Dwyer et al. 1993; Dwyer and Erdahl 1995). Results, however, have varied by voltage, distance from the electrode, duration of exposure, and developmental stage of the eggs when exposed to electroshock. Furthermore, some experiments involved voltages and durations of exposure outside the range to which fish or eggs would normally be exposed during typical electrofishing.

Godfrey (1957) reported mortality rates for brook trout eggs exposed to 150 or 550 V DC (0.6 or 1.7 A; voltage gradient within the water was not reported), for 30–300 s, and 0.3–3.7 m from the electrodes at various developmental stages. There were no indications that egg mortality resulted from electroshock treatment at the lower

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Received October 28, 1998; accepted April 30, 1999

voltage level. At the higher voltage, however, mortality of brook trout eggs electroshocked during early development (6 d postfertilization) ranged from 5% to 100% and varied by duration of electroshock and distance from the electrodes. In contrast, mortality of eggs electroshocked at either voltage during late-eyed development (44 d postfertilization) ranged from 0% to 10%.

Dwyer et al. (1993) reported similar results for rainbow trout *Oncorhynchus mykiss* eggs at various developmental stages exposed to 340-V pulsed DC (0.6 A; 0.9–1.0 V/cm) for 10 s. Percent mortality for eggs exposed to electroshock was significantly higher from handled controls at early developmental stages (2–10 d postfertilization), but was not significantly different from handled controls at late developmental stages (12–26 d postfertilization). Mean mortality ranged from 20% (18 d postfertilization; handled control = 20%) to 58% (8 d postfertilization; handled control = 30%). In addition, Dwyer et al. (1993) reported that the greatest mortality from mechanical (eggs dropped 15 cm onto a soft plastic bumper) and electrical shock occurred at the same developmental stages. The eggs, however, were more susceptible to mortality from mechanical shock than electrical shock at early developmental stages.

Another study with cutthroat trout *O. clarki* did not indicate a difference in mortality between control eggs and eggs at four developmental stages exposed to 30- or 60-Hz, 150-V pulsed DC (~1.4 V/cm) for 10 s (Dwyer and Erdahl 1995). There was greater mortality, however, for eggs exposed to 30- or 60-Hz, 225-V pulsed and continuous DC (~2.2 V/cm). Also, a complex pulse pattern resulted in greater mortality at 350 and 450 V compared to controls. The investigations of Dwyer et al. (1993) and Dwyer and Erdahl (1995) demonstrate that effects of electrical shock on fish eggs are dependent on species, waveform, and voltage level.

The goal of my study was to help assess the negative effects of electrofishing on mortality of Arctic grayling eggs. The research objectives were to examine the mortality rate of eggs from electroshocked parents (experiment 1) and the mortality rate of eggs electroshocked after fertilization (experiment 2).

Methods

In early May 1994, at a weir-trap site at Moose Lake, Alaska (62°07′N, 146°05′W), several hundred mature Arctic grayling were captured and retained in holding pens. On 9 May 1994, 60 females and 60 males were selected and randomly divided into two treatment groups of 30 females and 30 males each. One group was electroshocked and the other was not (control group). Fish were held separately by treatment group and sex until they were spawned.

For electroshock treatment, Arctic grayling were placed 10 at a time in a holding pen (1.22 × 1.22 × 1.22 m) and electroshocked for 5 s with a Coffelt Mark-10 variable voltage pulsator (VVP) backpack electroshocker powered by a Honda 350EX gasoline-powered generator. The anode consisted of an aluminum hoop attached to a 1.5-m handle and connected to the VVP with a 1.8-m coil cord. A 1.8-m steel cable served as the cathode. Electrical output settings were 200-V, 60-Hz pulsed DC and 50% duty cycle at 1.3 A. Water conductivity was 340 μS/cm and water temperature was 5°C. The anode was placed in the center of the holding pen and moved toward the fish. These conditions resulted in the fish being exposed to an average voltage gradient similar to field conditions (0.14–1.40 V/cm). The exact voltage gradients to which each fish was exposed was not known, but galvanonarcosis was sufficient in all fish to allow them to be easily netted from the water.

During spawning, a procedure was followed that provided each male in a treatment group (adults shocked or not shocked) an equal opportunity to fertilize the eggs of each female in that group. Eggs were removed from females by excising the abdominal wall so that the eggs flowed into a spawning pan. From the eggs of each female, a 10-mL sample was taken and added to a pool of eggs for that treatment group; the excess eggs were discarded. The pool of eggs was mixed and divided into thirty 10-mL samples; a different male's sperm was added to each aliquot. These eggs were again mixed and a small amount of water was added to activate the sperm. After 1–2 min, the eggs were washed to remove excess sperm and debris. Eggs of each treatment group were placed into 1-L containers for transport to Clear Hatchery. The two egg containers were placed in a cooler and lightly iced to maintain a temperature of approximately 3.5°C. The eggs were flown to the hatchery within 5 h.

The eggs, without regard to their condition, were volumetrically enumerated at the hatchery and placed in uniquely numbered fiberglass-screen baskets. These baskets were placed into trays for incubation. The water flow was 15–20 L/min and water temperature was gradually raised from 3.2°C

to 11.0°C. The eggs were treated with a 1:600 formalin drip solution for 15 min every other day to control fungal infection.

Experiment 1.—Eggs from control and electroshocked fish were kept separate in the identifiable fiberglass-screen baskets. Six baskets (three replicates from shocked fish and three replicates from control fish) of approximately 600 eggs each were placed into trays for incubation. Exact counts of eggs within each basket were recorded. One replicate each of shocked and control fish was placed side-by-side in a single tray to minimize front to back variation within a tray. Each replicate was placed in a separate stack of trays. The mean proportion of egg mortality was then compared between the two groups. The comparison was made using a one-tailed *t*-test between the proportion of eggs that died in each group before the eyed stage of development.

Experiment 2.—Eggs from control parents and eggs from electroshocked parents were kept separate in the identifiable fiberglass-screen baskets. A total of 168 baskets (3 replicates × 7 egg-developmental stages × 4 electroshock levels × 2 groups of parents) of approximately 100 eggs each were placed in trays for incubation and treatment. Six additional baskets (three from each group) of approximately 100 eggs each were placed in trays to be used as reference eggs for classifying the stage of egg-development at the time of treatments. The baskets were arranged within the trays by a randomized block design: one replicate per stack, four baskets placed within one tray, and the control and electroshocked parent of the same treatment placed side-by-side within a tray. Disturbance to trays was kept to a minimum, and all baskets within one tray received treatments on the same day. On the day of each designated stage of development, the predetermined baskets were removed one at a time, placed within an electroshocking tub, electroshocked at the specified level (high, medium, low, or none) for 5 s, and placed back in the tray. Exact counts of eggs within each basket were recorded. On each day of treatment, a sample of eggs from the reference group was retained and referenced by number of days postfertilization, temperature units (TU) postfertilization, stage of development, and a physical description.

The electroshocking tub was a one-piece, molded, rigid plastic tray with metal electrodes at each end that spanned the complete cross section of water in the tank. Electrical wire connected the electrodes to a Coffelt model 15 VVP, which delivered a uniform electrical field to the water. Levels of electroshock used for treatments were high (1.30–1.50 V/cm), medium (0.80–1.00 V/cm), low (0.30–0.50 V/cm), or none. The settings on the VVP were adjusted to achieve desired voltage gradients at 60 Hz and 50% duty cycle. To ensure consistent voltages within the ranges, power was turned on and average voltage gradients measured with a voltmeter after the initial power surge, but before the eggs were placed in the center of the shocking tub.

Analysis of variance (ANOVA) was used to examine the differences among the mean mortality rates of the main effects and interactions before the eyed stage of development. The main effects were parents (not electroshocked or electroshocked), electroshock treatment of eggs (none, high, medium, or low), and seven stages of development. Mean mortality rate data were normalized using an angular transformation of the proportion of dead eggs (Zar 1984).

Results

Fork lengths of the Arctic grayling used in the experiments ranged from 263 to 362 mm for females and 254–378 mm for males. Mean fork lengths for the electroshocked Arctic grayling were 323 mm for females and 316 mm for males; those not electroshocked were 318 mm for females and 313 mm for males. There were no significant differences between the lengths of Arctic grayling electroshocked and not electroshocked (males, $D = 0.17$, $P = 0.79$; females, $D = 0.20$, $P = 0.59$).

Experiment 1

Mean egg mortality rate was 0.020 for Arctic grayling eggs from parents that were not electroshocked compared to 0.036 for eggs from parents that were electroshocked ($t = -2.956$, df = 4, $P = 0.022$).

Experiment 2

Classification of Arctic grayling egg developmental stages from reference eggs at the time of electroshock treatment ranged from the morular stage through final stages of epiboly (Table 1).

The ANOVA indicated that all main effects were significant with no interactions (Table 2). The greatest mean mortality rates occurred at 70 TU postfertilization (Figure 1). At this stage of development, mean mortality rate was 0.117 (SE = 0.005) for Arctic grayling eggs that were electroshocked at the high level (1.30–1.50 V/cm) and were from parents that were electroshocked before spawning. By comparison, mortality rates were lower for eggs that were electroshocked at the high

TABLE 1.—Mean egg mortality rates of electroshocked Arctic grayling eggs by parents (not electroshocked or electroshocked), electroshock level (none, low, medium, or high), time of treatments (day postfertilization), number of temperature units (TU) postfertilization, and developmental stage.

			Mean egg mortality rates							
			Eggs shocked (parents not shocked)				Eggs shocked (parents shocked)			
Day	TU	Stage	None	Low	Medium	High	None	Low	Medium	High
2	8	Morular	0.017	0.024	0.035	0.045	0.024	0.036	0.049	0.070
4	22	Gastrular	0.030	0.036	0.043	0.043	0.051	0.044	0.051	0.082
6	38	Epiboly	0.033	0.046	0.037	0.054	0.054	0.045	0.060	0.095
8	54	Epiboly	0.040	0.033	0.056	0.058	0.046	0.048	0.067	0.098
10	70	Epiboly	0.035	0.044	0.065	0.079	0.057	0.071	0.090	0.117
12	86	Epiboly	0.032	0.037	0.047	0.074	0.046	0.065	0.074	0.099
14	102	Epiboly	0.028	0.036	0.053	0.061	0.043	0.052	0.066	0.072

level and were from parents that were not electroshocked (0.078; SE = 0.005); rates were still lower for eggs that were not electroshocked and were from parents that were not electroshocked (0.035; SE = 0.003). The lowest mortality rates occurred at 8 TU postfertilization (Figure 1). At this stage of development, mean mortality rate was 0.017 (SE = 0.002) for eggs not electroshocked and parents not electroshocked, 0.023 (SE = 0.002) for eggs not electroshocked and parents electroshocked, and 0.070 (SE = 0.004) for eggs electroshocked at the high level and parents electroshocked (Figure 1).

Whereas the effects were significant but with no interactions among main effects, Duncan's multiple range test was performed a posteriori to determine significance within the effects. The results of these comparisons indicated significant differences ($P < 0.05$) between the mean mortality rates for:

(1) Arctic grayling eggs electroshocked and parents electroshocked (0.062) compared to eggs electroshocked and parents not electroshocked (0.043);

(2) all combinations of eggs electroshocked by level of electroshock (high = 0.075, medium = 0.057, low = 0.044, and none = 0.038);

(3) eggs electroshocked at 8 TU (0.043) compared to all other times (22 TU = 0.050, 38 TU = 0.056, 54 TU = 0.060, 70 TU = 0.078, 86 TU = 0.066, and 102 TU = 0.057);

(4) eggs electroshocked at 70 TU compared to all other times;

(5) eggs electroshocked at 22 TU compared to 8 TU, 70 TU, and 86 TU;

(6) eggs electroshocked at 86 TU compared to 8 TU, 22 TU, and 70 TU.

TABLE 2.—Analysis of variance of electroshocked Arctic grayling eggs showing degrees of freedom, sum of squares (SS), mean of squares (MS), *F*-values, and *P*-values by main effects and interactions (P = parents, E = level of electroshock, and D = egg developmental stage).

Source	df	SS	MS	*F*	*P*
P	1	0.0783	0.0783	87.93	0.0001
E	3	0.1460	0.0487	54.64	0.0001
P × E	3	0.0039	0.0013	1.45	0.2330
D	6	0.0661	0.0110	12.36	0.0001
P × D	6	0.0023	0.0004	0.43	0.8594
E × D	18	0.0149	0.0008	0.93	0.5472
P × E × D	18	0.0088	0.0005	0.55	0.9271

Discussion

The results of this study support the hypothesis that mortality of fish eggs is influenced by electroshock. Furthermore, this study suggests that mortality of fish eggs from electroshock is related to the magnitude of the electroshock, the stage of egg development, and whether the parents were electroshocked or not. The sample sizes used in these experiments enabled detection of small differences in mortality between the control groups and the electroshocked groups.

For practical purposes, the differences in mortality rates were negligible and should not preclude using electroshock to capture Arctic grayling, as long as the intensity of electroshock is similar to that used in this study. For both Arctic grayling experiments, egg mortality rates were low and difference in mortality rates between controls and electroshocked groups were typically less than 5 percentage points and in the worst case less than 10 percentage points; the difference was less than 2 percentage points between eggs from parents electroshocked and parents not electroshocked in experiment 1. Mortality was highest for Arctic grayling eggs electroshocked during middle to late epiboly. This occurs at 50–90 TU postfertilization,

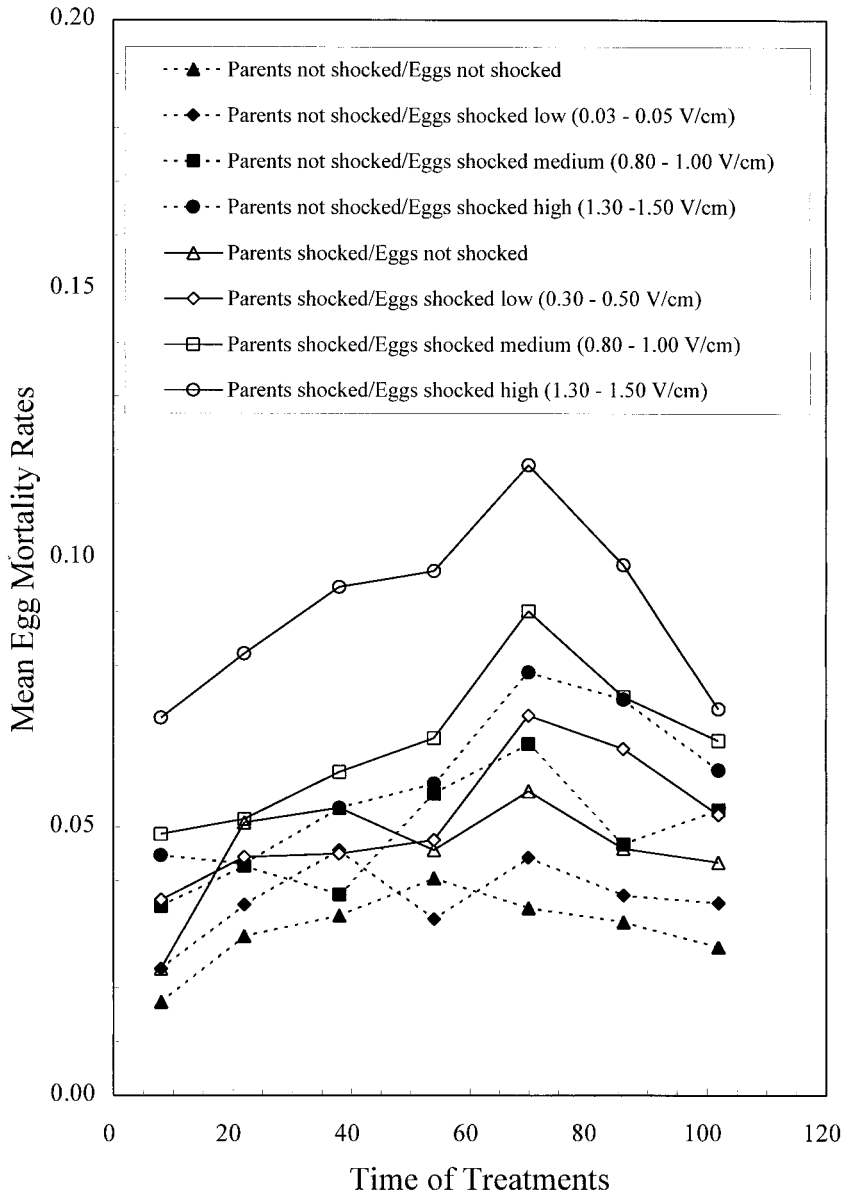

FIGURE 1.—Mean mortality rates for electroshocked Arctic grayling eggs by time of treatments (temperature units postfertilization), parents (not electroshocked or electroshocked), and electroshock levels (none, low, medium, or high).

which is 7–13 d after spawning at 7°C average water temperature (middle May for most interior Alaska rivers). Thus, the effects of electroshock on the mortality of Arctic grayling eggs, even though minimal, may be further reduced by not electroshocking during the time of increased egg sensitivity.

Fishery biologists routinely accept harm to individual fish as a cost of gaining valuable information. The difference in mortality between the control and electroshocked groups should be considered a cost of obtaining information, which should be compared with the costs of not sampling (management risks associated with lack of information) and the costs of sampling by other methods. Benefits of electrofishing, other than sampling efficiency, should also be factored into the consideration. For example, Mitton and McDonald

(1994) reported that rainbow trout experienced reduced adverse response to air exposure when handled under the mild narcosis following exposure to pulsed DC.

Biologists proposing to use electrofishing in areas where Arctic grayling are present can evaluate the costs and benefits of such sampling a priori. Knowledge of the harm to individual eggs from electrofishing can be equated to costs to the population. Along with mortality rates, probabilities of being exposed to lethal levels of electroshock should be considered when determining the costs to the population. For most sampling schemes, only a proportion of the population is exposed to the lethal levels of electroshock (Schill and Beland 1995). Investigators, however, should be aware that as capture probability increases egg mortality as a function of population size might also increase.

The results of this study indicate, even in situations where the probability of exposure is as high as 0.30 (extreme case for Arctic grayling studies in interior Alaska), the cost to the population of using electrofishing is low (equivalent to not allowing $<1\%$ of spawning females the opportunity to spawn). For some sampling strategies or for populations restricted to small areas, the risk to the population may be greater due to higher capture probabilities or chances of multiple captures. This can be evaluated by considering the mortality rates estimated from this study, the probability of lethal exposure, male: female ratios, percentage of stock that already spawned, and percentage of eggs that will be at the sensitive stage of development at a given time.

Acknowledgments

The author appreciates the help and comments from Peggy Merritt, Bob Clark, James Reynolds, Patricia Hansen, and Mike Wallendorf. Special thanks are given to the personnel at Clear Hatchery for the use of hatchery facilities and technical help. In addition, I thank those who helped with the fieldwork: Eric Adey, Bob Clark, Matt Evenson, Doug Fleming, Jerry Hallberg, Pat Houghton, Peggy Merritt, Bill Ridder, Dave Stoller, Tom Taube, and Charmi Weker. The U. S. Fish and Wildlife Service provided partial funding for this study through the Federal Aid in Sport Fish Restoration Act (16 U.S.C. 777-777K) under project F-10-10, Job R-3-2 (b) and F-10-11, Job 3-2(b).

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